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(54) SEMICONDUCTOR DEVICES

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to semiconductor devices comprising a semiconductor body, two regions of the body being of opposite conductivity type and different conductivities and forming therebetween an electroluminescent p-n junction, the body having a surface at which radiation emitted by the p-n junction emanates.

It is known that devices comprising a semiconductor crysal with an electroluminescent p-n junction generally have a low light radiation output and dissipate a great amount of heat and that, in general, their light output diminishes with increase in temperature. For this reason, it is known to provide an opaque base on which the crystal body is generally mounted at the surface opposite the surface at which the radiation emanates so that the greatest possible portion of the developed heat is conducted away. Such a base does not absorb the heat of the body part adjacent the said surface at which the radiation emanates.

In order to increase the efficiency of such a known device, in which the junction is obtained by impurity diffusion into the semiconductor body, it is preferred, as is known, to arrange for the radiation emanating surface of the body to be a surface of the lower doped of the said two regions of the crystal. Between the p-n junction and the said surface the emitted rays traverse low absorption crystalline layers, termed dielectric type layers since the most highly doped region has a considerable absorption of the metallic type. However, such a known device exhibits a poor transfer of the emitted light radiation because it forms a selective filter absorbing the photons of an energy exceeding 1.40 eV, which are the very photons emitted in great numbers by the p-n junction.

According to the invention, a semiconductor device comprises a semiconductor body, two regions of the body being of opposite conductivity types and different conductivities and forming therebetween an electroluminescent p-n junction, the body having a surface at which radiation emitted by the p-n junction emanates, and structural means which are associated with the mounting of the body, substantially transparent to radiation emanating at the said surface and permit in operation of the device thermal coupling of the said surface to a substantially radiation transparent coolant material other than the semiconductor body material and in contact with the said surface so as to increase the heat dissipation of the said surface and so obtain under normal operating conditions such a temperature gradient between the said p-n junction and the said surface that the absorption curve of the part of the body through which the radiation passes from the said p-n junction to the said surface is displaced to lower wavelengths and absorption loss of the radiation passing therethrough is reduced.

The part of the body through which the radiation passes from the said p-n junction to the said surface may comprise the one of the said two regions which has the lower conductivity type and an absorption of the dielectric type.

As will be explained hereinafter with reference to Figures 2a and 2b, the said temperature gradient obtained is chosen in accordance with the absorption curve displacement necessary to obtain the required reduction in absorption of the radiation passing from the p-n junction to the said surface and the required increase in both intensity and energy of the maximum emission from the said surface. Thus, the said temperature gradient obtained may be such that the absorption curve of the said part of the body through which the radiation passes is displaced by at least 70 Å, and maximum emission from the said

surface may occur for radiation having an energy exceeding 1.4 eV.

It may be advantageous to shape the body and/or the said structural means to form a lens. Thus, the said structural means associated with the mounting of the body may be shaped to form a lens having a part-spherical surface, of which the aplanatic point nearest the centre of the sphere is located in the vicinity of the said p-n junction.

The refractive index of the substantially radiation transparent coolant material may be chosen to be substantially the same as that of the semiconductor body material. In this case, a so-called aplanatic structure can be obtained such that almost all rays emitted by the junction towards a part-spherical surface (Weierstrass sphere) of the structural means will emanate since total internal reflection at the radiation emanating surface is then suppressed for the major part. Moreover, with such an arrangement the angular aperture of the emanating radiation in the air is such that its sine is equal to the inverse of the refractive index of the portion of the Weierstrass sphere for the emitted light and the resulting emanating radiation is restricted to a cone of small aperture, instead of being dispersed in a space angle of 2π ste radians.

The said structural means may include cooling vanes on an outer surface of the device.

In one form, the said structural means comprises a solid body of the substantially radiation transparent coolant material, which solid body is in contact with the said surface and has a fairly good thermal conductivity for example that of alumina or beryllia.

In another form, the said structural means comprises a substantially radiation transparent envelope portion which permits in operation of the device thermal coupling of the said surface to a substantially radiation transparent liquid coolant provided in the envelope portion in contact with the said surface.

The liquid coolant employed is chosen for both its thermal properties and its optical properties. The liquid coolant and the envelope portion traversed by the emanating radiation may form the whole optical output system of the electroluminescent device. The refractive index n_2 of the liquid coolant concerned may in particular be chosen in connection with the refractive index n_1 of the semiconductor crystal and with the refractive index n_3 of the surroundings so that definite properties of the optical system are obtained. For example, reflection may be reduced by providing for n_2 a value approximately equal to $\sqrt{n_1 . n_3}$.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 is a sectional view of a first electroluminescent device;

Figures 2a and 2b are graphs showing absorption curves and light emission curves respectively for electroluminescent devices, and

Figure 3 shows a sectional view of a second electroluminescent device.

The electroluminescent device shown in Figure 1 comprises a semiconductor body 1. Two regions 3 and 4 of the body 1 are of opposite conductivity types and different conductivities and form therebetween an electroluminescent p-n junction 2. The p-type region 3 is of higher conductivity than the n-type region 4 and is formed for example, by impurity diffusion into the body 1. In operation of the device, light radiation emitted by the p-n junction 2 passes through the lower conductivity n-type region 4 to a surface of the body at which it emanates. The said surface is firmly coupled to a substantially radiation transparent coolant block B associated with the mounting of the semiconductor body 1 and in contact with said surface thereof.

The block B is of alumina or beryllia and has a mass and volume considerably greater than the semiconductor body 1 and in operation of the device increases the heat dissipation of the said surface to obtain under normal operating conditions such a temperature gradient between the said p-n junction 2 and the said surface that the absorption curve of the region 4 of the body 1 through which the radiation passes from the said p-n junction 2 to the said surface is displaced to lower wavelengths and absorption loss of the radiation passing therethrough is reduced.

The temperature gradient arises since increased heat dissipation of the said surface maintains the n-type region 4 traversed by the emanating radiation at constant temperature, while the p-type region 3 is heated by the passage of the current and soon attains its equilibrium temperature. Thus, the temperature of the crystal layers traversed by the emanating radiation is lower than that at the junction, and this reduces significantly the absorption loss of the radiation passing therethrough so that the efficiency of the electroluminescent device is considerably improved.

Although the lower doped region 4 in the device of Figure 1 is of n-type conductivity, it will be obvious that a low doped material of p-type conductivity may be employed, in which, for example, by diffusion, a highly doped n-type region is formed. In this case, the radiation passes through p-type material to reach the surface at which it emanates, but the advantages of a cooling block B on that surface are maintained.

The curve 21a of Figure 2a illustrates the variation of the absorption coefficient αN (ex-

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pressed in $cm.^{-1}$) of an electroluminescent device as a function of wavelength λ (expressed in Angström) of the radiation emitted by the electroluminescent p-n junction of the device; the curve 22 of the Figure 2b illustrates the variation of the spectral emission $\frac{d\eta}{d\lambda}=f(\lambda)$ of the p-n junction of the same device as a function of the energy (expressed in electron volts) of the emitted radiation, η being the total output of the p-n junction of the device. The curve 22 is drawn empirically and a value 100 is given to the maximum S of $\frac{d\eta}{d\lambda}$. These two curves 21a and 22 relate to a particular electroluminescent device not in accordance with the present invention and at its equilibrium temperature. The light flux actually emitted by this device is illustrated by the curve 23a, which is a combination of the curves 21a and 22, whilst the maximum emission is designated by X.

It will be apparent that each energy E there corresponds a wavelength λ. Therefore, the values of E and λ in Figures 2b and 2a respectively are plotted on corresponding axes so that they may be superimposed.

In operation of a similar device which however, in accordance with the present invention, comprises the means mentioned hereinbefore to obtain the temperature gradient specified hereinbefore, there occurs a displacement of the absorption curve 21a towards the position 21b, which corresponds to the lower wavelength. The displacement shown in this example in Figure 2a is at least 70 A. The curve 22 remains substantially unchanged. For a given wavelength, for example 8,800 Å, the spectral emission of the junction does not vary, whilst the light absorption loss diminishes. As a result, the curve of the light flux emitted by the electroluminescent device thus cooled is displaced from 23a to 23b, and the maximum emission occurs at Y and has a higher intensity and energy than the emission X. As is shown in Figure 2b, the maximum emission from the surface occurs for radiation having an energy exceeding 1.4 eV; thus, the photons having an energy exceeding 1.4 eV are absorbed to a considerably lesser extent.

Figure 3 shows a particularly advantageous embodiment in which a liquid coolant circulates across a spherical lens (Weierstrass sphere).

The device shown in Figure 3 comprises a disc-shaped semiconductor crystal body 1. Adjacent one of the faces of this body 1, an electroluminescent p-n junction 2 is formed, for example by diffusion. The p-n junction 2 emits light radiation in operation of the device and it separates an n-type region 4 of the body 1 from a p-type region 3. On the surface of the region 3 is deposited a reflecting metal to form a mirror 5. The body 1 is welded at 8 to a metal base 6 on the same side as the mirror 5 but beyond the latter and by means of a soft solder, for example tin. The metal base 6 is extended on the side remote from the body 1 by a tube 6a which serves as the negative terminal of the device. The surface 7 of the body 1 opposite the base 6 is perfectly flat and polished and is in contact with a cooling liquid circulating through space 9a. This space 9a is bounded by a rigid, transparent wall 9, for example of quartz, which forms a spherical lens arranged so that the p-n junction 2 is disposed in the vicinity of the aplanatic point of the latter nearest its centre. The wall 9 is sealed to the base 6 of high conductiviy, for example of nickel copper, by means of an adhesive material 10, for example an epoxy resin. The wall 9 has two apertures in which sleeves 11 are sealed through which the cooling liquid can flow. It is preferable for the liquid to have a refractive index near that of the semiconductor body 1, and, when the body 1 comprises gallium arsenide, methylene iodide of refractive index 1.75 may be employed as the liquid.

A cylindrical metal pin 12 of high conductivity, for example of silver-plated copper is arranged on the free face of the mirror 5. This contact may advantageously be established by soldering, provided the soldering method does not adversely affect the optical properties of the mirror and no point of the reflective surface is altered.

A rigid tube 13 of insulating material, for example of glass, is arranged between the base 6 and the pin 12; the space 14 between the tube 13 and the body 1 on the one hand and between the base 6 and the pin 12 on the other hand is filled with an insulating material, for example an epoxy resin, for ensuring the mechanical disposition of the assembly.

The pin 12 is longer than the tubes 6a and 13 so that it has a free end to form the positive terminal of the device.

Many modifications are possible within the scope of the invention as defined in the appended Claims. In the device of Figure 1, the body 1 could be cooled by a less bulky block B provided with cooling vanes. In the device of Figure 3, the wall 9 could be provided with similar cooling vanes, which under given conditions could prevent a liquid from circulating. The liquid is then cooled by means of the vanes.

WHAT WE CLAIM IS:—

1. A semiconductor device comprising a semiconductor body, two regions of the body being of opposite conductivity types and different conductivities and forming therebetween an electroluminescent p-n junction, the

body having a surface at which radiation emitted by the p-n junction emanates, and structural means which are associated with the mounting of the body, substantially transparent to radiation emanating at the said surface and permit in operation of the device thermal coupling of the said surface to a substantially radiation transparent coolant material other than the semiconductor body material and in contact with the said surface so as to increase the heat dissipation of the said surface and so obtain under normal operating conditions such a temperature gradient between the said p-n junction and the said surface that the absorption curve of the part of the body through which the radiation passes from the said p-n junction to the said surface is displaced to lower wavelengths and absorption loss of the radiation passing therethrough is reduced.

2. A semiconductor device as claimed in Claim 1, wherein the semiconductor body is of gallium arsenide.

3. A semiconductor device as claimed in Claim 1 or Claim 2, wherein the part of the body through which the radiation passes from the said p-n junction to the said surface comprises the one of the said two regions which has the lower conductivity.

4. A semiconductor device as claimed in Claim 3, wherein the one of the said two regions which has the lower conductivity is n-type.

5. A semiconductor device as claimed in any of the preceding Claims, wherein the said temperature gradient obtained is such that the absorption curve of the said part of the body through which the radiation passes is displaced by at least 70 Å.

6. A semiconductor device as claimed in any of the preceding Claims, wherein maximum emission from the said surface occurs for radiation having an energy exceeding 1.4 eV.

7. A semiconducor device as claimed in any of the preceding Claims wherein the said structural means associated with the mounting of the body are shaped to form a lens having a part-spherical surface, of which the aplanatic point nearest the centre of sphere is located in the vicinity of the said p-n juncion.

8. A semiconductor device as claimed in any of the preceding Claims, wherein the refractive index of the substantially radiation transparent coolant material is chosen to be substantially the same as that of the semiconductor body material.

9. A semiconductor device as claimed in any of the preceding Claims, wherein the said structural means includes cooling vanes on an outer surface of the device.

10. A semiconductor device as claimed in any of the preceding Claims, wherein the said structural means comprises a solid body of the substantially radiation transparent coolant material, which solid body is in contact with the said surface.

11. A semiconductor device as claimed in Claim 10, wherein the coolant material is alumina.

12. A semiconductor device as claimed in Claim 10, wherein the coolant material is beryllia.

13. A semiconductor device as claimed in any of Claims 1 to 9, wherein the said structural means comprises a substantially radiation transparent envelope portion which permits in operation of the device thermal coupling of the said surface to a substantially radiation transparent liquid coolant provided in the envelope portion in contact with the said surface.

14. A semiconductor device as claimed in Claim 13, wherein means are provided for passing the liquid coolant through the envelope portion.

15. A semiconductor device as claimed in Claim 13 or Claim 14, wherein the semiconductor body material is gallium arsenide, and the liquid coolant is methylene iodide.

16. A semiconductor device as claimed in any of Claims 13 to 15, wherein the envelope portion is of quartz.

17. A semiconductor device substantially as herein described with reference to Figure 1 of the accompanying drawings.

18. A semiconductor device substantially as herein described with reference to Figure 3 of the accompanying drawings.

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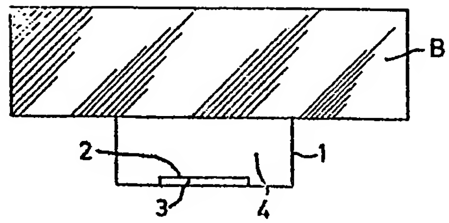

FIG.1

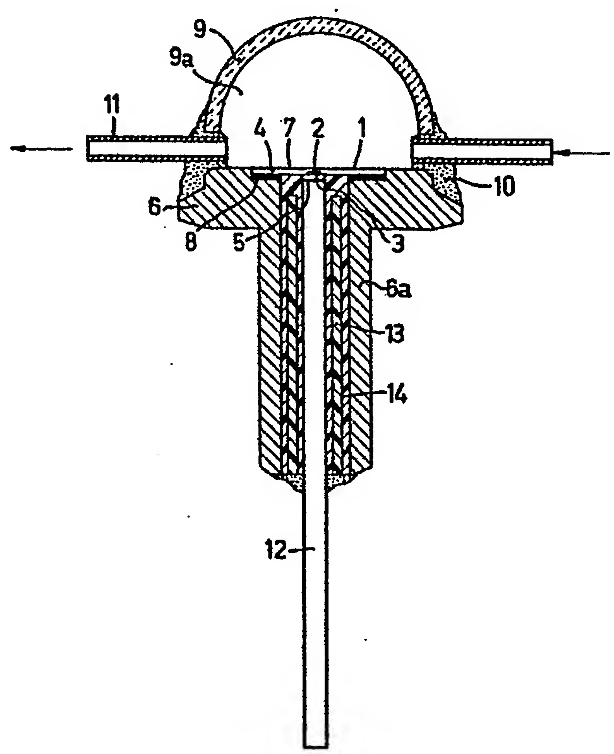

FIG.3

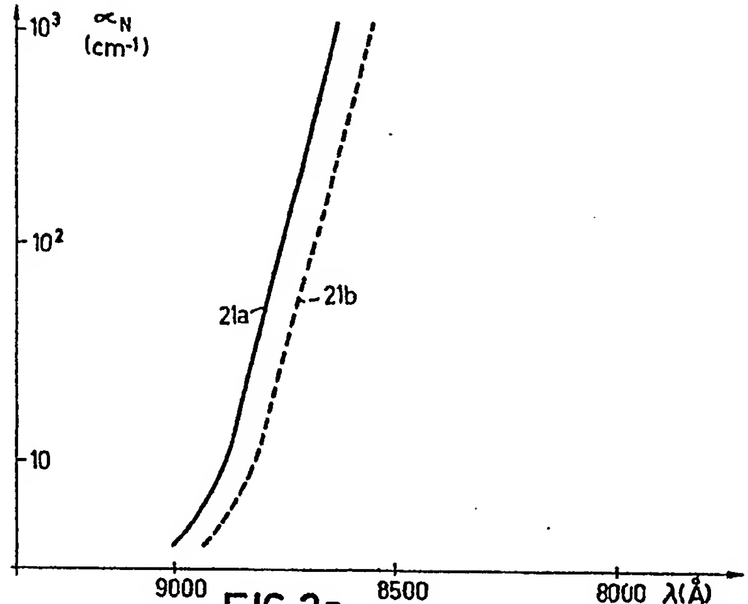
10^3
α_N (cm^{-1})
10^2
10
21a
21b
9000
8500
8000
λ(Å)

FIG.2a

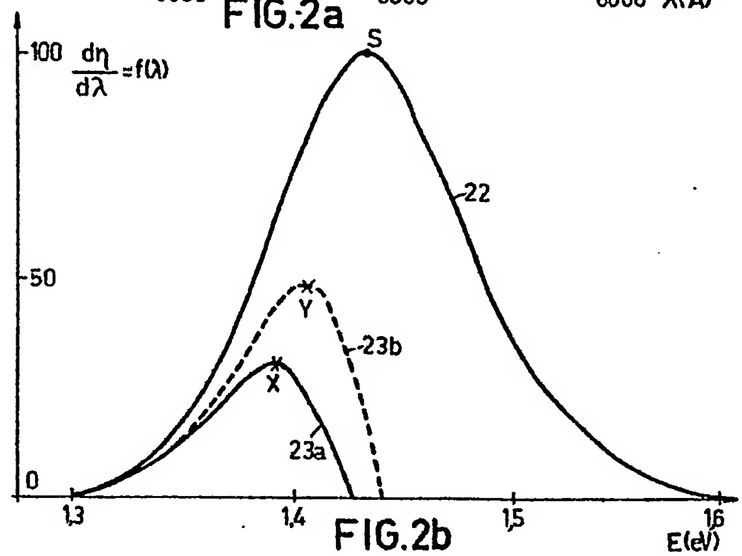
100
$\frac{d\eta}{d\lambda}=f(\lambda)$
S
22
50
Y
23b
X
23a
0
1,3
1,4
1,5
1,6
E(eV)

FIG.2b